Nuclear INFORMATION

Greater St. Louis Citizens' COMMITTEE FOR NUCLEAR INFORMATION

VOL. II No. 9 ST. LOUIS, MISSOURI JULY, 1960

MORE ON PLOWSHARE

ELECTRICITY FROM NUCLEAR EXPLOSIONS

by Christoph Hohenemser

ONE of the most talked-about proposals in Project Plowshare is the scheme to convert heat produced by an underground nuclear explosion into electric power. Gerald Johnson of the University of California Lawrence Radiation Laboratory explained this proposal to the Joint Congressional Committee on Atomic Energy last March as follows:

> The simplest scheme is based on the observed result from underground explosions that about 1/3 of energy release of the (nuclear) explosive is deposited in melted rock in the form of heat at high temperature. To this end various naturally occurring materials were analyzed and it was concluded that salt offered perhaps the best possibility. With the simplest concept, nuclear explosions deep in salt domes would produce large pools of melted salt. The energy could then be recovered by driving some working fluid, like water, through it to produce hot gas or steam. Theoretical calculations indicate that by multiple firings in the same location, as much as 50 percent of the total energy released could be recovered. Assuming a 30 percent efficiency of conversion of recovered heat to electrical power, it is conceivable that fuel costs could be reduced to a fraction of one mil per kilowatt hour. Using published A.E.C. charges, and assuming 1 million ton (TNT equivalent) explosions are used, the fuel cost is 6 mils per kilowatt hour. This is to be compared with the average U.S. fuel cost of 2 mils per kilowatt hour.

Johnson then describes a more efficient method, which involves excavation of the explosion chamber to its final size, and then the explosion of the device in water surroundings. He explains that this is more efficient as to heat loss, but adds that there are some technical difficulties in the huge excavation required. (See "Digging the Big Hole" in March 1960 bulletin.)

Statements like this, given to congressional committees, often represent the basis for justifying expenditure of public funds on such projects. It is therefore of interest to examine this statement to determine to what degree its conclusions are justified by available facts.

Cost Analysis is Confusing

Johnson's statement on costs is confusing. On the one hand he maintains that fuel costs could be reduced to a *fraction of a mil* per kilowatt hour, a figure which is *less than* 50% of the U.S. average conventional fuel cost. On the other hand, in the next sentence, he states that according to present prices, the cost of nuclear fuel from a 1 megaton (1 million ton TNT equivalent) explosion with 15% overall efficiency, will be 6 *mils*, a figure which is *three times* the conventional fuel cost.

In addition, he fails altogether to discuss the cost of recovering the heat and turning it into electrical power. In conventional power plants this is done by means of a steam-driven generator. The same method would be used in a nuclear plant. Cost of steam-driven generator operation is about 4 mils per kilowatt hour, which must be added to the fuel cost. *Therefore the cost of conventional electricity is 6 mils and that of nuclear electricity, at least 10 mils.* Data is from the AEC.[2]

Problem of Radioactive Steam

In addition, the problems of piping large quantities of heat from the explosion site deep in the earth to the generator, may bring the cost even higher. In the proposed scheme, steam is to be pumped through the explosion chamber. The steam that returns to the surface will be radioactive. According to A.E.C, reports,[3] the solution of this problem requires recycling the steam, or chemical removal of the radioactivity. If these complications add 2 mils to the cost, we obtain twice the conventional price.

The statement to the congressional committee assumes, without further qualification, that a series of explosions could be set off at the same site. This is essential to economic operations, because of the large investment involved in the power-converting machinery. However, analyses of the effects of underground explosions published by the AEC,[4] indicate that multiple explosions are probably not very practical. Each explosion forms a chimney of crushed rock pointing upward toward the surface of the earth. Since crushed rock is porous, and incapable of absorbing much of the blast of a second explosion, a second shot may break the surface of the earth and release harmful radioactive gases. If the number of nuclear explosions at each site is limited by this difficulty, Johnson's cost estimates are, again, too optimistic.

Salt Domes the Only Feasible Sites

Johnson says that salt domes would make good locations for the experiment. But it is also pertinent that salt domes are probably the *only* places where large underground explosions are at all feasible. Salt domes are at once dry, and soluble in water. The dryness avoids contamination of groundwater – which would occur almost everywhere else; the solubility of salt makes the pre-explosion excavation at least tractable in comparison to insoluble strata. With these limitations, it appears that large-scale power projects are limited to salt dome areas, of which there are only a few in this country, and these, mostly located where big power projects are not needed – for example in New Mexico.

(Continued on page 3)

Copyright 1960, Greater St. Louis Citizens' Committee for Nuclear Information.

MINING FOR RADIOACTIVE ISOTOPES

by Brian Pate

WHEN a nuclear bomb is set off underground, huge quantities of radioactive isotopes are produced, some of which may be useful for scientific experiment, medical treatment, or industrial processes. One of the proposals of Project Plowshare is for mining operations to recover these isotopes. In considering this proposal, one is concerned with three classes of these materials.

Fission Products

First are the so-called fission products, those radioactive atoms formed from uranium by nuclear fission. Whether the explosive used is of the fission (A-bomb) or fusion (hydrogen bomb) type, fission products are produced in large amounts. In the latter case, a fission explosive is used to trigger the fusion explosion, and some types of fusion device are contained in a uranium jacket, which adds greatly to the quantities of fission products formed.

However, a mixture of radioisotopes differing only slightly in composition from those produced in an explosion is continuously produced in the operation of nuclear reactors, and the quantities of fission products available from this source have become so large that their disposal is a source of embarrassment. Further, reactor-made fission products, if they are to be separated and prepared for use, are available in a relatively convenient and concentrated form, as a by-product in the chemical processing of reactor-fuel. In contrast, fission products from an underground nuclear explosion would need to be extracted from large quantities of mineral debris, a situation many times less attractive. Further, the mining of large quantities of radioactive rock for this purpose, as described in Plowshare literature, seems to the writer a singularly unpleasant prospect.

Isotopes formed by Neutron Capture

The second class of radioactive isotopes to be considered are those formed when a neutron (produced in the fission or fusion reaction) is captured by the nucleus of an atom. Cobalt-60 is a familiar example of such a material, and is produced when natural stable cobalt (Co^{59}) is inserted into a nuclear reactor and captures neutrons. Likewise, plutonium (Pu^{239}) is the final product when a neutron is captured by a uranium (U^{238}) nucleus. Such materials are made in nuclear reactors, but some, particularly those of long life such as Co^{60} and Pu^{239}; involve very long periods of irradiation for the production of substantial quantities. This is a consequence of the small number of neutrons available in reactors. In a nuclear explosion on the other hand, especially in the case of a fusion one, the numbers of neutrons available are very much greater than in a reactor. Consequently, large amounts of these very useful isotopes would be made in an instant; in favorable circumstances, many times more than would be made in years of reactor operation. However, the problem of recovering useful quantities would present the same difficulties previously mentioned. On balance, the lengthy reactor irradiations seem to be a better proposition. In the case of shorter-lived materials, which must be prepared and used before they are lost by radioactive decay, there seems to be little doubt that production via nuclear explosions becomes less and less a practical proposition.

Multiple Neutron Capture

Finally one must consider those materials which are formed by neutron capture as described above, with the difference that many neutrons must enter the starting nucleus instead of just one. Any technological application of these materials is probably less important than their preparation for scientific use. Our understanding of nuclear structure is materially advanced by study of nuclei of extraordinary composition (for example, abnormal ratios of protons to neutrons), and multiple neutron capture is one way of making such nuclei. Multiple neutron capture does proceed in a reactor, but not very effectively. The quantity of material produced depends on the number of neutrons available in a given time interval, and in reactors, as we have seen, such numbers are relatively low. Also, if there is a relatively long time interval between the capture of separate neutrons, radioactive decay of the intermediates can occur to a greater extent, which tends to offset the sought-for effects of multiple neutron capture.

Advantage of Nuclear Explosions

Here nuclear explosions have a clear and definite advantage. In view of the enormously greater numbers of neutrons available, multiple neutron capture proceeds readily. Further, since neutron release is instantaneous, the capture of the desired number of neutrons is accomplished essentially before any decay can occur. In addition, the recovery problem now is not so severe, since for scientific experiments, only a relatively small fraction of the large yield produced by the explosion needs to be recovered from the debris. Indeed the feasibility of such an operation is not in doubt, since recovery of debris from the Mike thermonuclear explosion in 1952 led to the discovery of the new elements 99 (Einsteinium), and 100 (Fermium), formed by multiple neutron capture in uranium. Unfortunately, many of the most interesting materials which would be produced in a contained explosion, and which would be required for study, are of short life, and difficult, if not impossible, to recover.

In Conclusion

From the foregoing, it may be concluded that production and recovery of technologically useful quantities of radioactive materials could not reasonably be advanced as the sole reason for conducting a contained nuclear explosion. Nor is it obvious that these materials would be useful by-product of blasts conducted for other purposes, particularly in view of the recovery problem.

In the case of certain materials useful for scientific investigation however, and especially the third class discussed above, it seems likely that nuclear explosions may be a profitable, if not the only source. However, economic considerations probably preclude the use of explosions solely for such a purpose; to be feasible, the operation would presumably need to be combined with others of technological or scientific importance.

Many of the proposals advanced in connection with the Plowshare program (non-military uses of nuclear explosives), appear to feature a curious blend of fact and fancy – of well substantiated, realistic propositions and others whose feasibility seems highly dubious. Those involving isotope production seem to fall into the latter category, although often they are not spelled out in sufficient detail to allow thorough evaluation.

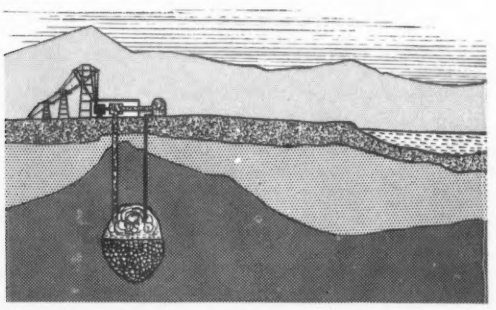
Continued from page 1

Probably the most important fact that the congressional testimony fails to bring out is that the economics of nuclear explosions completely rule out any explosion smaller than a megaton for power production. This is because nuclear explosives cost virtually the same, no matter what their power is.[5] For this reason, economy results from the use of very large blasts.

Shock Waves

Apart from the difficulties already mentioned, however, the use of a megaton nuclear explosion introduces a new – and quite serious – problem. If such an explosion is set off in a small hole (to avoid the expense of digging a big cavity at 10,000 feet underground), then seismic (earthquake) effects of the explosion may prove a prohibitive hazard. The figure, which is taken from an A.E.C. report on the power proposals[9], shows an underground explosion, a shaft with circulation pipes leading up to a power plant, *directly above the explosion*, and power lines going off into the distance. Yet according to the most optimistic A.E.C. data, seismic shock waves from a megaton explosion will cause damage as far as 19 miles away. If a less optimistic approach is taken, damage will extend to 76 miles from the explosion site.

It has been suggested in one A.E.C. report that 10 to 100 megaton explosions will have to be used in order to produce power competitive with present costs,[7] while another report suggests successive megaton shots every 10 to 12 days.[8] According to the most optimistic estimate, a 10 megaton explosion would cause some damage up to 43 miles, and a 100 megaton explosion, up to 100 mile. The predicted limits of damage would be four times these numbers if the pessimistic estimate is used.



The above estimates have been made from A.E.C. data, as noted. They are uncertain because of the scarcity of data bearing on this new technology. Complete, accurate calculations must await accumulation of more experimental information. On the other hand they are fairly well founded as *rough estimates* for typical geological situations.

Even such rough estimates indicate, however, that the cost or, indeed, the feasibility of nuclear power from contained explosions is considerably more difficult to estimate than has been generally appreciated. The underground nuclear explosion planned in New Mexico next January (Project Gnome) is, in part, designed to provide added information about the proposed power scheme. It remains to be seen whether this test will provide a better factual basis for the optimism express in the congressional testimony.

Neutron Experiments

by Franklin B. Shull

THE underground nuclear explosions of Project Plowshare may permit experiments that will advance our understanding of the atom. One of the most important problems in current physics is determination of the forces which hold together the atomic nucleus. All nuclei are composed of protons (positively charged particles), and neutrons (uncharged particles of nearly the same mass as protons). The nuclear forces acting between the members of a collection of protons and neutrons operate only over very short distances, for the atomic nucleus is some 10,000 times smaller than the atom itself. Revealing information about the forces within the nucleus can be obtained by studying what happens when a fast-moving neutron is made to collide with, or come very near, a particular kind of atomic nucleus.

A nuclear explosion produces, among other things, a concentrated burst of neutrons having enormous intensity enduring for an extremely brief time – about a hundred-millionth of a second. This single fact suggests the exciting possibility of performing certain experiments which would be impossible with conventional laboratory equipment. For example, to match the number of neutrons available from a nuclear explosion, a laboratory apparatus would have to run 3000 – 4000 years.

To be sure, the unusual character of the explosion as a research "tool" brings many complications but already, enough experience has been gained to show that these problems can be overcome.

"Project Gnome," established within Plowshare to plan ways of carrying out such neutron experiments, proposes that a 10 kiloton fission bomb be detonated 1200 feet down in a salt bed near Carlsbad, New Mexico. A 1200′ vertical access shaft would end at the beginning of a 1000′ horizontal tunnel which would curve near its far end, and then circle back on itself in a sort of buttonhook. The blast would occur at the tip of the hook. A straight evacuated pipe, 1000′ long and 14″ in diameter, would lead neutrons from the shot site back to the access shaft. Equipment for the proposed experiments would be put in "bays" dug in the sides of the horizontal tunnel. Cables leading back to the tunnel and up the shaft, would carry the data in the form of electrical impulses to recording apparatus on the surface.

(Continued on page 4)

NUCLEAR INFORMATION is published 9 times a year by the Greater St. Louis Citizen's Committee for Nuclear Information, No. 2 Oak Knoll, St. Louis 5, Mo.; PA 5-7055.

Editor: Florence Moog

Associate Editor: Phyllis McPheeters

Scientific Advisory Board: Howard Blossom, H. T. Blumenthal, M.D., Barry Commoner, Paul A. Doudna, John M. Fowler, Irwin H. Herskowitz, Gordon Lark, Norman E. Melechen, Florence Moog, John N. Ong, Jr., T. A. Pond, Eric Reiss, M.D., J. B. Reynolds, William W. Sleator, Jr., M.D.

Subscription rates:
Individual: $2 per year
Organization (6 copies each issue): $5 per year.

Continued from page 3 –

To see how a neutron experiment would be carried out in such a setting, consider the operation of a typical laboratory device, the fast-chopper neutron spectrometer at Brookhaven National Laboratory. The neutron source is a reactor, and a rotating wheel pierced by narrow slits is used to break up the flow of particles into brief bursts of neutrons (perhaps one millionth of a second in duration) at periodic intervals. Each burst contains neutrons which travel at a wide range of speeds. As these proceed through the apparatus, they become separated, the faster ones pulling ahead of the slower ones. After travelling 100 yards or so, the group of neutrons is well spread out. The neutrons then encounter other rotating wheels with similar slots, which are so synchronized with the slots in the first wheel as to select from the spread-out group of neutrons only those which have similar speeds or energy. These energy-selected neutrons then strike the experimental target and the appropriate data are recorded. This process is repeated with group after group at one energy. To take data at a different energy, it is necessary to reset the synchronization of the slotted wheels, and start over.

By contrast, a similar, explosion-initiated experiment would use a single burst of neutrons rather than a prolonged sequence of bursts. With only one burst, measurements would have to be made at all energies simultaneously. This technique is feasible, however, because of the enormous numbers of neutrons produced by a blast, which allow statistically significant data to accumulate even in a few thousandths of a second.

Actually, the experiment as described would offer no great improvement over existing techniques. The great potential lies in the fact that with such large numbers of neutrons, the experimenter can afford to lengthen the neutron flight path, thus spreading out the group even more. This in turn permits the selection of neutrons *in much narrower speed groups*. The resulting increase in the precision of energy determinations in neutron exments is what makes "Gnome" so attractive.

Another property of the neutron is its "spin," and certain experiments require an arrangement in which atoms are bombarded with a stream of neutrons which have an axis of spinning of a preferred, rather than random orientation. These immensely difficult "polarization studies," can also be improved by using neutron beams from nuclear explosions. Selection of preferred spin-orientations greatly reduces the useful number of neutrons in an experiment, so that availability of large flows of neutrons from an explosion is a big advantage. In some cases, where very great selectivity is required, the experiment cannot be done with conventional apparatus.

This evidence suggests that some real scientific gains can be made by carefully planned exploitation of underground nuclear explosions. But each experiment would be enormously costly. If such studies are only by-products of an otherwise useful blast, the cost probably is not prohibitive. But if the experiment is nearly all that such an explosion will accomplish, it is possible that the funds could be better used in other scientific work. At present, the Plowshare reports do not provide a basis for such an evaluation.

OUR AUTHORS . . .

this month are all from Washington University in St. Louis:

Christoph Hohenemser, graduate student in physics, is one of the authors of a report on atomic disarmament, "The Nth Country Problem".

Brian D. Pate, associate professor of chemistry, is a specialist in the chemistry of radioisotopes.

Franklin B. Shull, associate professor of physics, specializes in sub-atomic particles.

REFERENCES

1. Hearings before the Joint Congressional Committee on Atomic Energy, March 21, 22, 1960.
2. University of California Radiation Laboratory, Report UCRL 5253, p. 18, Sept. 8, 1958.
3. University of California Radiation Laboratory, Report UCRL 5677, p. 14, May 14, 1959. (See also Report UCRL 5253, pp. 20-23.)
4. Johnson, Higgins, and Violet, "Underground Nuclear Detonations", Journal of Geophysical Research Vol. 64, p. 1457, October 1959.
5. University of California Radiation Laboratory, Report UCRL 5676, p. 3, May 14, 1959.
6. University of California Radiation Laboratory, Report UCRL 5457, p. 8, Jan. 1959; Report UCRL 5676, p. 33, Report UCRL 5253, pp. 26-31, Sept. 8, 1959.
7. University of California Radiation Laboratory, Report UCRL 5677, p. 21.
8. Ibid, p. 53.
9. Ibid, cover.

Greater St. Louis Citizens'

COMMITTEE FOR NUCLEAR INFORMATION

Room 318, Museum of Science and Natural History
2 Oak Knoll Park
St. Louis 5, Missouri

NON-PROFIT ORG.
U.S. Postage
PAID
St. Louis, Mo.
Permit No. 841

Form 3547 Requested.